Physical Cosmology with the Sloan Digital Sky Survey

Kevork Abazajian, Salman Habib, and Yongzhong Xu (T-8), Daniel Holz and Michael Warren (T-6), Scott Dodelson and Josh Frieman (Fermilab/University of Chicago), Hume Feldman (University of Kansas), Katrin Heitmann (ISR-1), Lam Hui (Columbia University), and Adam Lidz (Harvard University);
habib@lanl.gov

The Sloan Digital Sky Survey (SDSS) is by far the largest astronomical survey project ever conceived (Fig. 1). It is producing a wealth of data on the clustering of mass in the universe (approximately 600 papers to date!). This dataset represents a defining challenge to theoretical cosmology. As the Los Alamos National Laboratory (LANL) theory team in the SDSS collaboration, we are developing the theoretical foundations and implementing the tools necessary to interpret data from the survey. This work includes gravitational lensing, Lyman-alpha systems, redshift distortions, and cluster mass distributions using advanced methods of particle simulation and computational hydrodynamics. This project represents a next-generation effort in the new era of precision cosmology.

The LANL theory effort with SDSS began officially two years ago. Previous to this, a research plan was established with colleagues at Fermilab. The key LANL contribution to SDSS is the large-scale simulation capability represented by the HOT (Hashed Oct-Tree) parallel tree code and MC^2 (Mesh-based Cosmology Code), a parallel particle-mesh (PM), and Hydro-PM (HPM) code. Computer time at LANL has been made available by the Institutional Computing Initiative. The initial plan focused on applying LANL simulations to the analysis and interpretation of the SDSS dataset. Topics included: the spectral index of the primordial power spectrum P(k) and its running from the SDSS Ly-alpha forest data, mock cluster catalogs and the cluster mass distribution, weak and strong lensing studies, and precision results for P(k) to investigate baryonic oscillations, nonlinear turnover, and constraints on neutrino masses. Redshift-space distortion and velocity field studies were also planned. We have since added projects that use the SDSS data directly (described below).

Simulation data from HOT will be used for constructing SDSS cluster mock catalogs using a constrained sampling technique. This ensures that the statistics of the simulated clusters are consistent with observations. In another collaboration, the mass function of dark matter halos as computed by HOT is being used to model bias in the SDSS

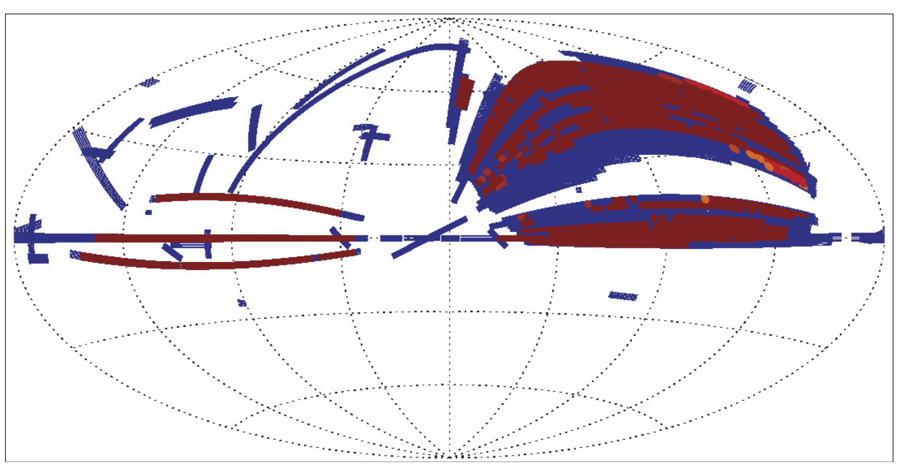

Figure 1—
The present sky coverage of the Sloan Digital Sky Survey.

galaxy-galaxy lensing analysis. While the SDSS cluster catalog is relatively shallow, the development of such techniques is essential for the extraction of information regarding dark energy from deep next-generation cluster surveys such as the Dark Energy Survey, SNAP, and LSST.

The SDSS Ly-alpha dataset (6000 quasar lines-of-sight) is being analyzed using the HPM capability of MC^2 (Fig. 2). Constraints on the amplitude of the power spectrum and running of the spectral index should be available in a few months. The methodology employed has been demonstrated using Keck data [1]. MC^2 data will also be made available to the angular correlation function team in SDSS searching for baryonic oscillations and the (redshift-dependent) nonlinear turnover in P(k). MC^2 simulations for weak lensing analyses are now being analyzed by university collaborators. Extension of this work will be applied to next-generation weak lensing surveys.

In terms of direct involvement in SDSS data analysis, we have participated in the measurements of P(k) and resulting constraints on cosmological parameters [2] and in the SDSS-WMAP cross-correlation analysis to measure the integrated Sachs-Wolfe effect [3]. The positive signal found for dark energy was cited by *Science* magazine as its number one breakthrough for 2003. Currently, work is ongoing on a project to measure the angular power spectrum on scales less than 1 Mpc to greater than 100 Mpc.

The distance to early-type galaxies in the SDSS can be measured using the fundamental-plane technique. Since the galaxy redshifts are known, the line-of-sight peculiar velocity can now be found. Using this information, we are aiming to measure the relative pairwise velocity as a function of the galaxy separation for early-type galaxies in SDSS. At present 40,000 galaxies are available and this number is expected to double. This technique can be used to constrain the matter density of the universe and the amplitude of P(k) making relatively few assumptions, and, because of the depth of SDSS, has the potential to reach out to scales where the universe makes its transition from a nonlinear regime to statistical homogeneity. The catalog has been checked for quality control and estimator biases. Mock catalogs will be essential for the success of this project and are being generated using HOT and MC^2 N-body simulations.

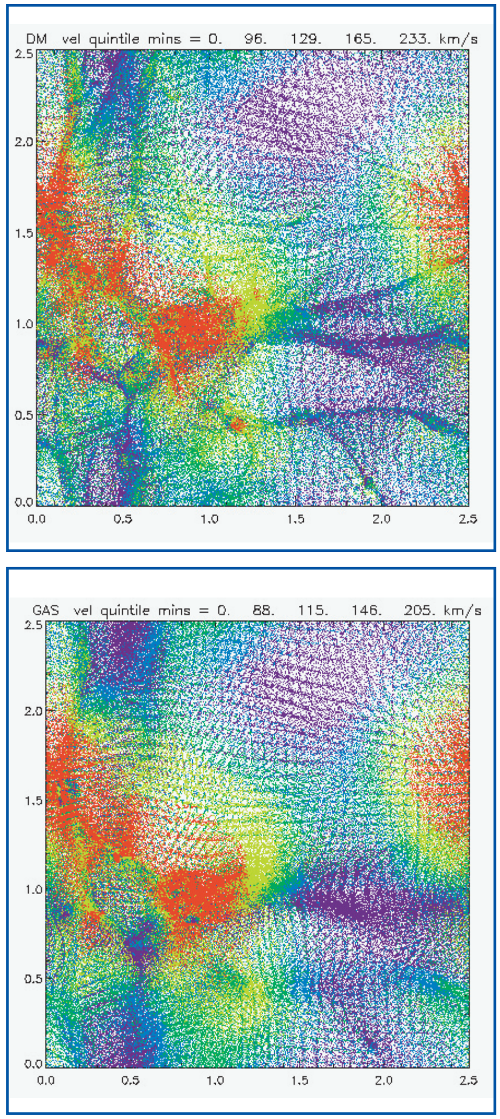

Figure 2—
(a) The projected dark matter and (b) baryon (gas) distribution from a test HPM simulation with MC^2. The gas density profile is smoother because of pressure forces. The length scale shown here is 2.5 Mpc.

[1] A. Lidz, L. Hui, K. Heitmann, S. Habib, M. Rauch, and W.L.W. Sargent, Los Alamos National Laboratory report LA-UR-04-0072 (2004).
[2] M. Tegmark et al., *Phys. Rev. D* **69**, 103501 (2004).
[3] R. Scranton et al., *Phys. Rev. Lett.* (submitted).